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Total Ownership Cost Reduction Case Study:

AEGIS Microwave Power Tubes

31 May 2006

by

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The goal of this research is to provide a descriptive case study that will chronicle the operational and engineering processes that were used to reduce the total ownership cost for the AEGIS Shipbuilding Project while dramatically improving the mean time before failure. The processes used to achieve these results are important to understand in light of current reduction in various resources in different programs. In particular, this case highlights the role that Naval Warfare Centers can and do play in the acquisition process.

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Abstract

This research provides a descriptive case study that chronicles the operational and engineering processes that were used to reduce total ownership cost for microwave power tube components of the AEGIS Shipbuilding Project while dramatically improving their mean time between failure. The processes used to achieve these results are important to understand in light of the current reductions in various acquisition support resources including financial support, manpower and in-house technical expertise. In particular, this case highlights the role that Naval Warfare Centers can and do play in the acquisition process and its supporting engineering disciplines.

Keywords: AEGIS, Total Ownership Cos, TOC, Mean time between failure, MTBF, Microwave Tubes, MWT, business processes, Cross Field Amplifier, CFA

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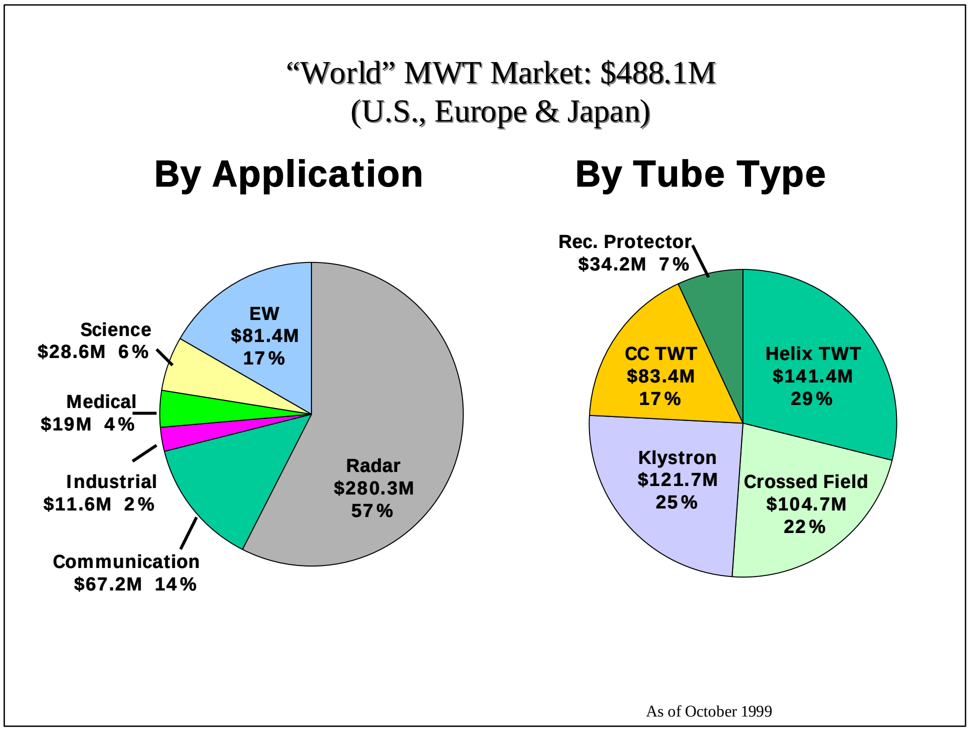
Introduction

All ships of the AEGIS fleet, indeed the entire fleet, require Microwave Tubes (MWT) (Hoffer, 2003). Early in the development of the AEGIS program, one such MWT, the Cross Field Amplifier (CFA) proved to be a substantial cost driver. This study documents the identification of the root causes of this problem and the process that not only eliminated the problem but also yielded both an increase in tube mean time between failure (MTBF) and a much-lowered total ownership cost (TOC). This case chronicles the methods used to reduce TOC in a program that serves as an example of early spiral development. The objective of this study is to understand the process and recognize the business issues within it that are essential to maintaining system combat capability, enhancing system affordability and reducing TOC.

Background

The AEGIS shipbuilding program, arguably one of the largest and most successful acquisition programs in the Department of Defense (DoD), has provided the Navy with over 90 capable surface combatant ships. AEGIS ships now make up the majority of the Navy's destroyer and all of its cruiser fleet. MWTs are used in 27 CGs and 48 DDGs to date (Hoffer, 2003) and this number continues to grow. MWTs are the primary components in the radar systems of the AEGIS fleet. There are numerous other shipboard systems that utilize MWTs:SPS-48, SPS-49, MK-99, USC-38, and Phalanx to name just a few. Throughout the world, 57% of MWTs are used in radars; the manufacture of radar MWTs alone is a $280.3M market. Figure 1 shows the world market for MWTs by application and type (Dutkowski, 2004-2005).

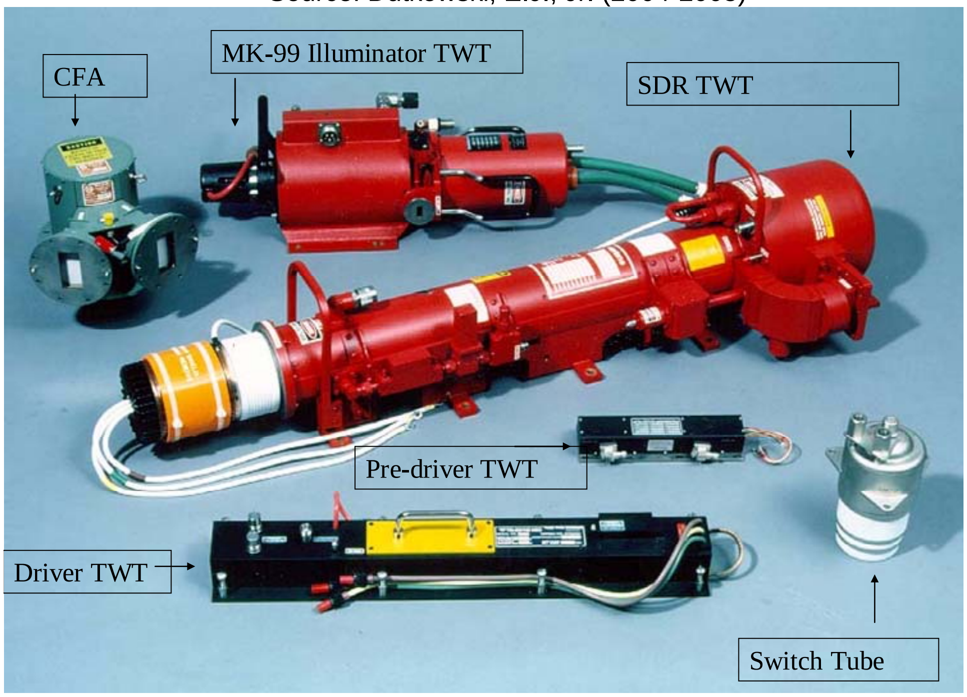
Figure 1. The World Market for MWTs by Application and Type
Source: Dutkowski, E.J., Jr. (2004-2005)



Greene's Story

It was the early 1980's, the height of the Reagan defense build-up, and AEGIS was the centerpiece of the Navy's shipbuilding program. Rear Admiral James B. Greene, Jr. was the project manager (PM) for the AEGIS shipbuilding project. Initial deployment of AEGIS cruisers was completed and departmental focus was shifting to include lifecycle cost control as well as enhanced system operational availability (Ao). At the same time, the DDG-51 class was in engineering design and development. The weapons systems of the ships were heavily dependent on MWTs with Cruisers using 176 per system and Destroyers 90. Figure 2 provides a picture of the MWTs used on these ships. Not surprisingly, MWTs became cost drivers for TOC and also for system, and thus ship, Ao.

Figure 2. Tubes used in the AEGIS Weapons System
Source: Dutkowski, E.J., Jr. (2004-2005)



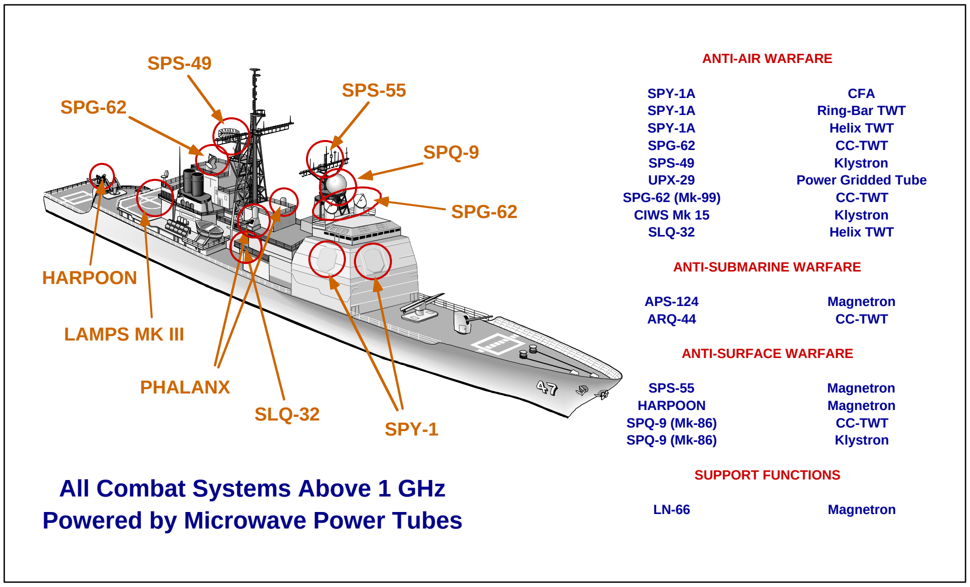
In a regular monthly meeting with his staff, Admiral Greene was briefed on the status of MWTs. These meetings were held to review program execution, cost and schedule issues. Staff noted that the unit cost of MWTs had exceeded their expectations and that the mean time between failure (MTBF) of MWTs was very low. This situation had existed for some time with no improvement in sight without added management attention.

The MWT

The AEGIS weapons system had been in design and development for several years. Program decisions were based on, among other considerations, reliability estimates that included MWT reliability, cost estimates, and maintenance concepts. The use of MWTs in combat systems was extensive. The principals in the program—designers, planners, and decision-makers including contractors—knew the extent of the applications of MWTs in AEGIS ships. There was not just one type of MWT; several different MWTs were utilized in AEGIS ships, for instance, Cross Field Amplifiers (CFAs) in the radar systems and traveling wave tubes (TWTs) in

electronic warfare systems. Though there were numerous applications of MWTs then, now they are used in even more war-fighting applications. Figure 3 (Dutkowski, 2004-2005) shows a current example of MWT utilization in a CG-47 class ship.

Figure 3. CG-47 Class MWT-based Systems
Source: Dutkowski, E.J., Jr. (2004-2005)



As can be seen, many shipboard systems depend on MWTs. Figure 4 (Dutkowski, 2004-2005) illustrates the usage of MWTs in various such systems. The prevalence of MWTs in Navy ships is shown in Figure 5.

Figure 4. Usage of MWTs
Source: Dutkowski, E.J., Jr. (2004-2005)

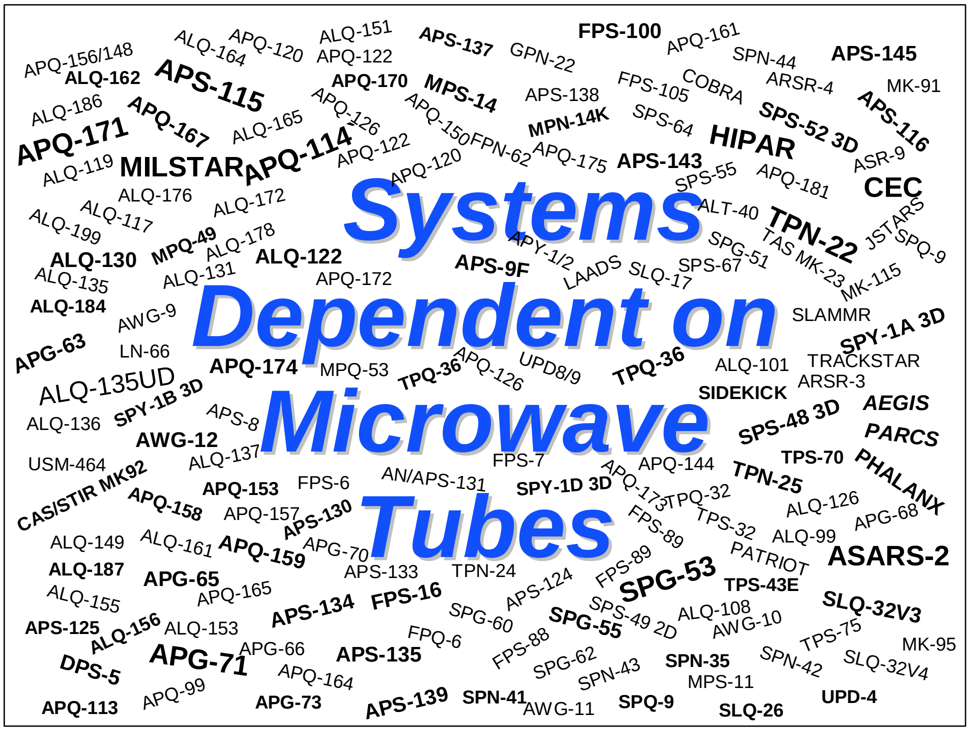
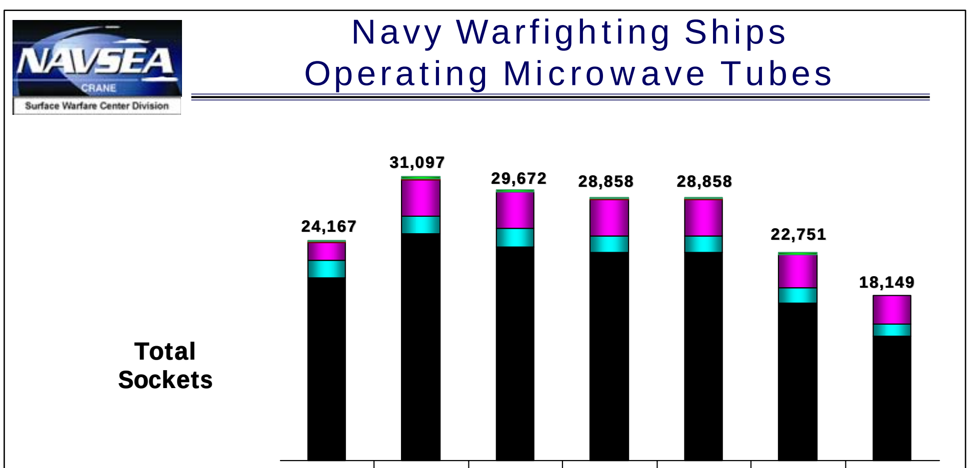


Figure 5. Current MWT Usage in the US Navy
Source: Dutkowski, E.J., Jr. (2004-2005)



	2000	2005	2010	2015	2020	2025	2030
Mine Warfare	192	192	192	184	184	169	0
Submarines	76	76	69	69	69	54	33
Expeditionary Forces	1884	3979	3937	3932	3932	3573	3092
Aircraft Carriers	1998	2008	2010	1844	1844	1678	1344
Surface Combatants	20017	24842	23464	22829	22829	17277	13680

Total Ownership Cost Driver

When RADM Greene was briefed by his staff, the manufacture of MWTs was an industry that was very process and material dependent with little process or configuration control. The tubes were, indeed, state-of-the-art technology for that era but they were, in the current vernacular, early “spirals” (Apte 2005). Each succeeding version was an evolved version of the previous one. This situation presented great challenges to the team to put controls in place in the manufacturing plants to reduce manufacturing risk. Through contract requirements (requiring configuration and process controls), investment of government dollars into product improvements and continual monitoring of product, these factors could be mitigated over time.

Given the unit cost and MTBF data of the MWTs, the PM estimated tube replacement costs to be $1M/ship/year. Based on a then projected AEGIS fleet size of 40 ships, Admiral Greene calculated total annual cost for CFA tube replacement to be $40M—just to keep the AEGIS radar systems operational.

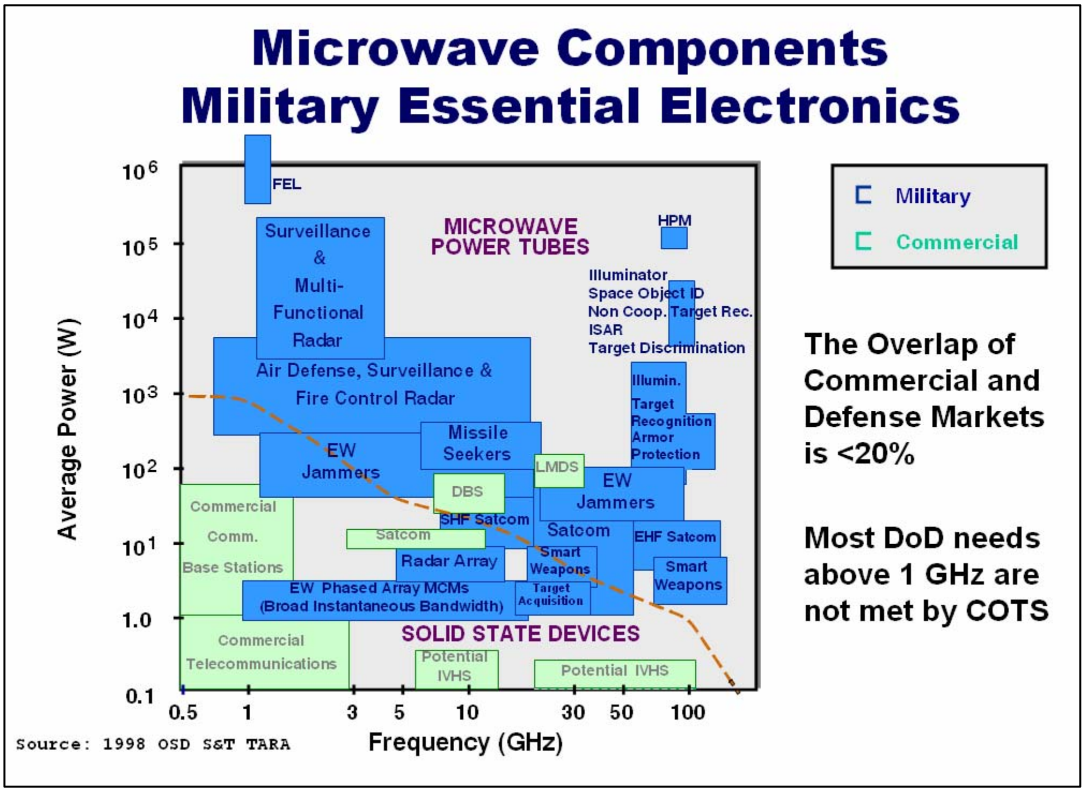
The Problem

The data presented to Admiral Greene highlighted that MWTs were costly to replace and costly to produce. With MTBF in the range of 1,300-12,000 hours and a high unit cost, they were a major contributor to TOC.

The key players in the program understood the risks involved in the ”black art” of MWT production. This set the stage for tasking Warfare Center engineering specialists to take charge of this issue and craft engineering and logistics solutions. In any case, performance-versus-cost of MWTs was a problem and not using the tubes was not a technical solution.

A parallel and nagging question of the day was that if MWTs are so difficult and expensive to produce (and at the same time essential to so many applications of AEGIS), then why not replace the tubes with solid-state components? This issue took considerable engineering expertise and time to answer with Figure 6 being developed to silence the critics. Simply put, the solid-state technology at that time was not mature enough to replace the vacuum devices.

Figure 6. Microwave Components Military Essential Electronics
Source: Dutkowski, E.J., Jr. (2004-2005)



The Opportunity

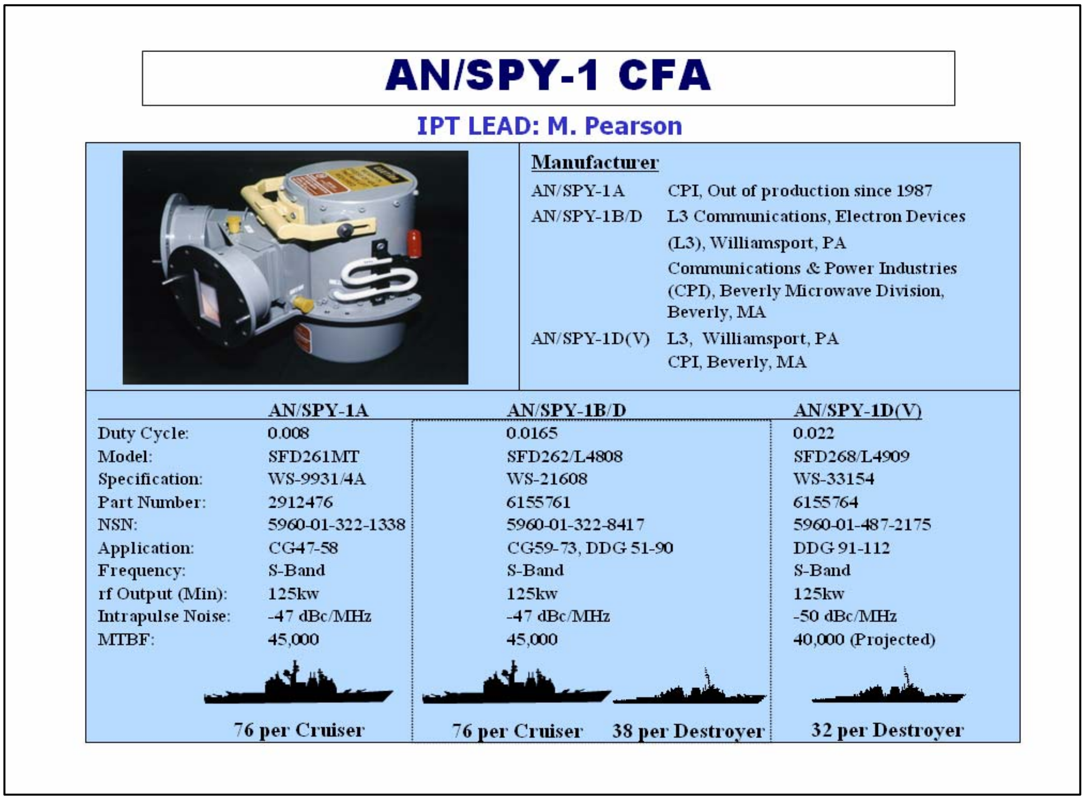
Admiral Greene was facing quite a few issues revolving around the MWT components. But an opportunity presented itself. There was soon to be a conference held at the Naval Postgraduate School (NPS) on MWTs. The CEOs of all the companies that provided MWTs to the AEGIS shipbuilding project were attending the conference. The companies would both benefit from the success of AEGIS and would suffer if the performance/cost of MWTs remained the same. Admiral Greene sensed the potential for turnaround.

Greene’s Solution

Admiral Greene decided that instead of treating adversity as a constraint, he was going to exploit the same to solve the problem. He made a pitch specifically to the CEOs of the vendor companies. Focusing on CFAs, he explained to them that the problem he was facing was that CFAs had an operating cost of $1M/ship/year.

He conveyed to them the criticality of CFAs to the AEGIS fleet. Figure 7 depicts the CFA and its prevalence in the AEGIS fleet. At the microwave power tube conference he challenged them, ”Propose something to fix this problem. Let us work together. As Project Manager, I promise you full cooperation. Let us collaborate and resolve this issue.” At Admiral Greene’s invitation, the CEOs came to his quarters in Hermann Hall at NPS. A frank dialogue at this meeting laid the groundwork for implementing a successful process that ultimately led to a reduction in TOC and an increase in MTBF for CFAs. Although limited contractually on the extent he could be involved in internal company affairs, Admiral Greene did offer all the CEOs the opportunity to have him speak to each of their work forces to underscore the importance of their efforts in this critical national defense program.

Figure 7. AN/SPY- 1 CFA
Source: Dutkowski, E.J., Jr. (2004-2005)



The Process

As he had agreed, Admiral Greene visited each of the tube production facilities with his staff. This staff included staff engineers, operations managers, and financial experts from the Naval Surface Warfare Center at Crane Indiana, the Navy's In Service Engineering Agent (ISEA) for microwave power tubes. He challenged his staff to devise a solution. He felt confident they could do so because of the technical competence they demonstrated through the years in combat systems engineering and in particular microwave power tube technology.

After initial evaluation, staff proposed a two-fold approach to the combined TOC/MTBF issues. The first was to assure an accurate diagnosis and repair of the tube (Hoffer, 2003); the second was an improved ability to locate and track all tubes that had been produced (Dutkowski, 2004-2005). Initial diagnostic trouble shooting

revealed a metallurgical problem. The anode of the CFA was made of high purity, electrical-grade copper which is quite soft. This copper also has a very low melting point. When a CFA turns on or during the change to a long waveform, the CFA has a tendency to arc between cathode and anode. Excessive arcing leads to premature failure and is detrimental to the overall performance of the amplifier. Admiral Greene's team discovered that the anode vanes were melting slightly and progressively due to arcing. The deterioration due to arcing was increasing—to the point that the tube would arc at shorter pulse lengths and at lower power levels. This erosion eventually led to tube failure. It was clear that better operating life could be obtained if the anode vanes could be prevented from melting due to arcing. The solution devised was to add a thin layer of molybdenum, which has a higher melting point than copper, at the ends of the anode vanes and to reduce the arcing by better processing of the tubes.

The second issue to be resolved was an inventory control issue. The CFAs were high value assets and capturing them for repair vice disposal was crucial. This required knowing where each tube was and then providing for their return to the designated repair facility. Additionally, tubes with the new modifications needed to be installed where and when appropriate so they could fit the empty sockets left by the un-improved tubes. Therefore, tracking the CFAs was vital. The team developed a method of serial number tracking of each tube. The principal behind it was the same as that behind the now common barcode and the recently introduced technology of radio frequency identification (RFID). The Crane team successfully implemented a serial number tracking program. The Crane team was successful for two reasons: they had in-house technical skills to successfully develop engineering solutions to the arcing problem and they had the managerial skills necessary to develop an effective inventory control and repair protocol. This process, in addition to configuration control of the manufacturing, added the ability to track changes introduced through the spiral development process to give visibility to the impact these changes had on performance.

At the next biennial conference, Admiral Greene presented the results to industry as a ”good improvement.” Thanks to the improved tracking and repair processes of CFAs, the MTBF had increased substantially—to about 5000 hours (Greene, 2004)—and the operating cost was reduced by a third. However, he challenged his staff and industry to keep building on the three pillars for success of the initiative: accurate tracking of tubes, maintenance of the knowledge base necessary to stay abreast of technical developments in the tube industry and continuous improvement of the tube production process.

After his departure from the program, these initiatives continued to thrive at Crane Naval Surface Warfare Center. It is still operating with increasingly impressive statistics: MTBF is up to 40,000-45,000 hours, and the cost per operating hour in 2002 dollars has been reduced to $0.45/socket from $8.20/socket as shown in Figure 8 (Dutkowski, 2004-2005).

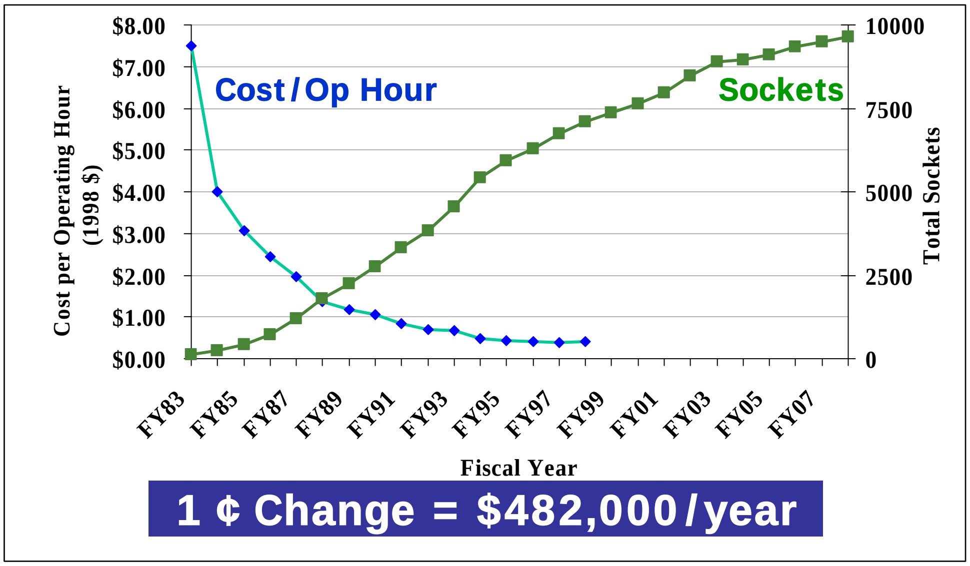
The Accomplishment

The success of initiatives such as inventory control using accurate tracking, maintaining technical knowledge base, and continuous improvement of the production process, has tremendous significance to the support of any combat system. The solution implemented regarding the CFA components in AEGIS is an excellent example of a successful pursuit of reduction of TOC (Boudreau & Naegle, 2003). The effort initiated in the mid-1980s is still paying off. The arcing that led to the melting of anodes (which, as mentioned above, precipitated the failure of CFAs—resulting in a very low MTBF) prompted a series of well-managed steps to continue to improve the tubes. Tracking of the tubes was essential for locating and tracking the result of the changes. This was an extremely valuable initiative since it helped reduce the cycle-time for repair and change insertion by the real-time feedback to the manufacturer. Knowing what caused the failure and where and when the failure occurred was critical to increasing operational availability. The ability to track the CFAs was critical to the success of the program. Likewise, an impressive string of engineering changes such as the modification in anode metallurgy, manufacturing processes improvements, controls, logistics, and

configuration control have led to an increase in the MTBF of the tubes from 6000 hours to 40,000-45,000 hours.

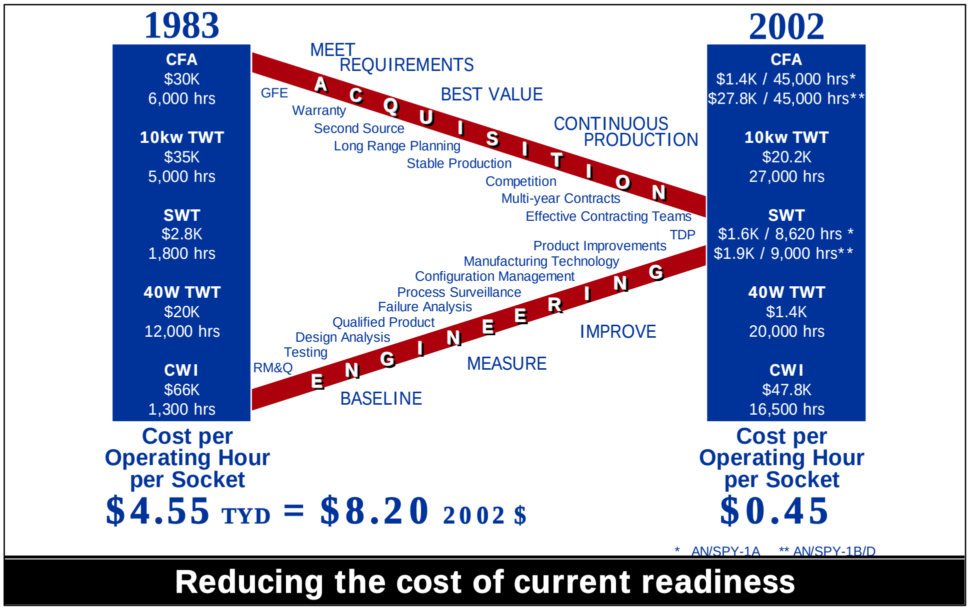
These improvements have reduced the frequency of corrective maintenance and, therefore, the operating and support (O & S) costs. The changes in vane tips, tracking of MWTs (so that the location and circumstances of MWT malfunctions are known), and extra attention to business issues have dramatically improved the reliability and availability of the host weapons system. Of note, this same modification of the vane tips has been implemented in two other CFA configurations thus using the learning to advance the design of new systems. Other AEGIS MWTs have also undergone additional improvements and have yielded added O & S cost savings. Progress in reducing the cost/operating hour of AEGIS CFA tubes is shown in Figure 8 (Dutkowski, 2004-2005).

Figure 8. Cost/Operating Hour History
Source: Dutkowski, E.J., Jr. (2004-2005)



Even if just a small amount is saved on each tube, due to the large number of tubes used in the fleet, savings can be substantial for a small change in life-cycle cost. The V-chart in Figure 9 shows that investment in engineering and management initiatives throughout the lifecycle of a system can dramatically reduce TOC. This initiative has found application in 27 AEGIS cruisers (each of which includes 76 CFAs) and 48 AEGIS destroyers (each equipped with 32 to 38 CFAs) to date. In 2002 dollars, the annual savings averaged about $1.9 million per AEGIS cruiser and $950 thousand per AEGIS destroyer.

Figure 9. AWS Microwave Tube Engineering/Acquisition Program
Source: Dutkowski, E.J., Jr. (2004-2005)



The Analysis

Several key factors contributed to the success of this initiative. The program achieved a high level of collaboration amongst all key parties including the Fleet, field activities and headquarters. In order for a project to succeed across functional departments such as design, planning, contracting and engineering, there needs to be a leader who will champion the new initiatives and processes. This leader, along with key team players, has to devise innovative programmatic and contractual provisions. Greene’s ability to integrate his team was a key element in that team’s success and he was able to leverage the existing AEGIS team to do so. The concept of an Integrated Product Team (IPT) is an initiative common today, but was not a by-word 20 years ago. Likewise, although theoretically the use of an IPT is an effective business tactic, the difficulty in its implementation can be overcome only if a clear focus and vision is maintained by the team leader.

In addition to the strength of Greene’s leadership, none of these successful steps could have been achieved without the in-house (government) technical

competence and knowledge of Greene's staff. In-house technical knowledge was essential to assuring industry collaboration. A knowledgeable (smart) buyer is essential in evaluating industry recommendations for technical and process changes. Consequently, retaining in-house expert technical personnel is critical to improving system operations and costs. These assets may be in the field or at headquarters or both, but they must exist on the government team.

The above discussion of the small industrial base and process/material dependent manufacturing of the CFA suggests that there are very few, sometimes no, manufacturers for customized defense products. Due to this lack of competition, integrity has to be maintained in writing the best value contracts. It has been proven in the private sector over and over again that competition breeds both diversity in products and helps the best among them to survive. The absence of competition in the manufacturing of some defense products adds responsibility to the program manager; he/she must ensure the quality of the product and contract. Therefore, evaluating best value contracts is key in this type of acquisition. Many times the government must buy critical product in a small production lot environment, precluding the ability to have a competitive contract situation. The small production lot environment requires competent government oversight to be effective. Again, one must have technically competent staff within the government to do so.

In addition, the production pipeline of such customized defense products has to be smooth to achieve significant cost savings. A disruptive supply will likely stifle MTBF improvements. The stop-and-start of production adds the disadvantage of a high fixed cost. Therefore continuous production is desirable. This requires a procuring agency that views long-term requirements and vendor loading versus the short-term (meet the current demand) perspective. This continuity is especially necessary when manufacturers are training workers for such tailored products. In the case of the CFA, the very stable AEGIS shipbuilding project provided just such a stable demand for CFAs

Business Issues

On the surface, this discussion is a simple success story of identifying CFA failures due to arcing and engineering their prevention by tracking and modifying the tubes, thereby increasing MTBF, and at the same time lowering production costs. What is impressive and powerful about this accomplishment is the process through which the problem was diagnosed and the cure implemented. “In my wildest dreams, I did not think we could come this far,” said Greene about the success of this program (Greene, 2004). What is crucial to this discussion is the recognition that this process has long-reaching roots in Acquisition strategy—then and now. This detection, analysis, and solution process encompasses profound technical, managerial, and policy issues. Some of the business issues this story highlights—such as organizational integration, evolutionary acquisition, theory of constraints, the six sigma/ continuous improvement theories of total quality management, outsourcing, operations management, and contract/cost/budgets, are instructive for any program manager.

The dramatic improvement implemented by Greene and his team was and is a result of organizational integration of key players, an IPT in today’s vernacular. This collaboration included the AEGIS Program Office, Communications and Power Industries (CPI, a vendor that was formerly part of Varian and provided the CFA), Crane Naval Surface Warfare Center, the Navy Man Tech Office, and *Raytheon* (the prime contractor). The collaborative effort for reduction in TOC and increase in MTBF of the CFA had two major facets: acquisition and engineering. Individuals from these disciplines formed the integrated product team.

The evolving production of the CFA reminds the researcher of the current strategy of Evolutionary Acquisition and its process of Spiral Development (Apte, 2005). There are similarities between the process through which the CFAs evolved and the current trends of incremental design and production based on the input of warfighters. Spiral Development is a set of acquisition activities that are incorporated in an evolving baseline using increments. Each increment increases the capability of the product. Each increment is completed at a rapid pace. Each increment builds

over each previous spiral. Since all the CFAs were customized products, each version that was produced was a modification of the previous version. The versions were redesigned based on user input so that the lessons learned from the previous version helped reduce the flaws in the production of the next version. Each increment included a reassessment of risks and assumptions. These are also the basis of Spiral Development. These days each increment creates a functioning prototype at the end of which lessons learned are evaluated; before starting the next increment, a decision is made about whether to proceed or not. In essence, the CFA evolution is an early example of what is now termed spiral development.

Numerous program challenges existed in the form of resources, constraints, new and evolving technologies, lack of understanding of failure root causes, and communications between program participants across the country to name a few. But, the theory of constraints suggests that such constraints can be exploited to the advantage of the system. In the presence of constraints, one need first identify the system constraints. Next, one should decide how to exploit them. Thirdly, one should subordinate everything else to this decision. Lastly, one should remove the system constraints to solve the problem. That is precisely what was done here. For example, Greene exploited the high unit production cost and low MTBF by challenging the manufacturers to discover a process which would deliver a quality tube to the program, increase MTBF and reduce TOC.

One of the important tools in Total Quality Management is the Cause-and-Effect diagram, sometimes known as the fish-bone or Ishikawa diagram. This diagram is used to sort out the causes of the problem. Brainstorming sessions of groups of personnel involved are required. These sessions help identify complete lists of causes of the problem and the relationship between causes and effects in a rational manner. This process educates everyone involved in the system regarding the causes and effects of the problem. This engineering process revealed the melting of the CFAs during arcing. By asking questions such as: Why did the tube fail? Why did the vanes melt? What was the cause of low melting point? Why cannot

the solid state be used? Greene's team was able to expose and correct the root cause of the low MTBF statistics for the CFAs.

The literature and current research in outsourcing indicates that outsourcing products, not service, is more advantageous to most systems, especially where the service involves the defense of a nation. Outsourcing the support of a weapon system eliminates the need for in-house technical knowledge. Absence of such personnel prohibits creative approaches to system failures. It also inhibits challenges to the industry that supports the same system. Decreasing or eliminating the retention of in-house experts in certain services may prove to be penny wise and pound foolish.

As noted earlier, the evolution of the AEGIS CFAs presents an early example of what is now termed spiral development. As such, since spiral development is the preferred acquisition strategy in DoD today, this CFA case has even more relevance. If new weapons systems in DoD are going to be largely spiral in nature, then there will be many future opportunities to replicate the CFA evolution. If TOC of weapons systems are to be constrained, then program officers must be prepared to emulate the CFA strategy described herein. This will require the maintenance of a technically competent work force both at program inception and during system deployment. This later role has been historically filled in the Navy by competent ISEAs resident in Naval Warfare Centers, which each specialize in particular technologies. The author suggests, using this CFA case as an example, that it is imperative that this skill set be maintained if DoD hopes to contain TOC in a spiral development world. Colvard and Doyle (2006) reach a similar conclusion albeit on a broader organizational scale.

The CFA case also raises the notion that it is crucial for a DoD entity to play a "stewardship" role when necessary to preserve DoD's ability to obtain an affordable product/process which is critical to national defense needs. Such a role is envisioned when products or processes have limited commercial interest and support, on-shore sources are non-existent or insufficient, and/or unique military

logistics requirements exist. In a stewardship role, a facility such as Crane Naval Surface Warfare Center would facilitate communication and knowledge sharing among industry, academia and military users of products and processes. The center would also maintain crucial capabilities and knowledge required for test and evaluation, Logistics, and for certain manufacturing and repair. This stewardship would also identify and assure support of technologies underlying the product or process. Last, but definitely not the least, there needs to be an entity that will serve as an advocate for programs targeted at maintaining the viability of the product or process and work to maintain a balanced budget strategy to support the critical industrial base. This notion makes yet another argument, proven in the CFA case, for retaining an in-house technically competent workforce and a Industrial Stewardship program.

One of the most important aspects of operations management is process management. Process management is an ongoing methodology for evaluating, analyzing, and improving the performance quality of a key business process. A process is evaluated by establishing process ownership, determining user requirements, and evaluating and rating the process. This process is then analyzed by benchmarking, developing and reviewing solutions with participants, and developing improvement plans. Process improvement is then achieved by implementing the process improvement plan, measuring the results, obtaining user feedback and, at the end, doing it all over again. Clearly, without such a continuous process improvement strategy, the CFA program would not have achieved such impressive results. Key to the success of this process is configuration control and the tracking of the product.

Conclusion

The goal of this research was to provide a descriptive case study that chronicled the operational and engineering processes used to reduce one aspect of the total ownership cost for the Aegis Shipbuilding Project. In the early days (circa 1983) of the Aegis Shipbuilding Project, the program office recognized that the numerous microwave tubes used in the Aegis radar system would significantly contribute to operational costs. As a result, an initiative was put in place to focus on substantially reducing these costs. The initiative was eventually applied across the whole spectrum of Navy microwave power tubes. This Reduction in Total Ownership Cost (R-TOC) effort has been extremely successful as various initiatives have driven down cost metrics (such as dollars/operating hour) while achieving a significant increase in MTBF. The engineering and management processes used to achieve these results are important to understand in light of recent manpower reductions in the services as well as an erosion of the in-house engineering skill base. In particular, this case highlights the role that Naval Surface Warfare Centers can and do play in the acquisition process. This case study validates these successes and identifies the underlying factors that catalyzed them.

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List of References

Apte, A. (2005, June), Spiral Development: A Perspective, (Acquisition Research Sponsored Report Series), Monterey, CA: Naval Postgraduate School.

Boudreau, M. W. & Naegle, B.R. (2003, September). Total ownership cost considerations in key performance parameters and beyond (Acquisition Research Sponsored Report Series). Monterey, CA: Naval Postgraduate School.

Colvard, J.E. & Doyle, J.H. (2006, February). We Need Scientists--Engineers More than Ever, U.S. Naval Institute Proceedings.

Dutkowski, E.J., Jr. (2004, September 2 through 2005, July 28). [Electronic Communication and phone interviews with Aruna Apte].

Greene, J.B., Jr. (2004, September 28 through 2005, December 2). [Interviews and Electronic Communication with Aruna Apte].

Hoffer, K. (2003, November 17). [Electronic Communication with Aruna Apte].

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Presentations, Publications and External Forums

Rendon, Rene. “Commodity Sourcing Strategies: Supply Management in Action.” Published as “Commodity Sourcing Strategies: Processes, Best Practices, and Defense Initiatives.” *Journal of Contract Management* 3, no.1 (2005): 7-21.

Doerr, Ken, Ira Lewis, and Donald Eaton. “Measurement issues in Performance Based Logistics.” *Journal of Public Procurement* 5, no. 2 (2005): 164-186.

Eaton, Donald, Ken Doerr, and Ira Lewis. “Performance Based Logistics: A Warfighting Focus.” *US Naval Institute Proceedings.* (In Press).

Doerr, Ken, Donal Eaton, and Ira Lewis. “Performance Based Logistics.” Presented to the International Defense Acquisition Resource Management Conference. Capellen, Luxembourg, 2004.

Kang, Keebom, and Ken Doerr. Workshop: Metrics and Performance Evaluation in Performance Based Logistics. Presented at Future Naval Plans & Requirements Conference. San Diego, CA. October 2005.

Boudreau, Michael, and Brad Naegle. “Total Ownership Cost Considerations in Key Performance Parameters and Beyond.” *Defense Acquisition Research Journal* 38, no.2 (2005): 108-121.

Boudreau, Michael, and Brad Naegle. Workshop: Setting up Acquisition for Total Lifecycle Supportability Performance. Presented at the Institute for Defense and Government Advancement Conference: Total Lifecycle Systems Management. Arlington, VA. 2005.

Kang, Keebom, Ken Doerr, Uday Apte, and Michael Boudreau. “Decision Support Models for Valuing Improvements in Component Reliability and Maintenance.” Submitted to the Journal of Defense Modeling and Simulation in July 2005 for possible publication. Currently the article is being reviewed by referees.

Franck, Raymond (Chip). “Business Case Analysis and Contractor vs. Organic Support: A First–Principles View.” Presented at the Western Economic Association International Annual Conference. San Francisco, CA. 5 July 2005.

Dillard, John, and Mark Nissen. “Computational Modeling of Project Organizations under Stress.” In review.

Dillard, John. “Centralization of Defense Acquisition Programs.” Accepted for publication in the Defense Acquisition Research Journal (2005).

Nissen, Mark E., and John Dillard. “Computational Design of Public Organizations.” In review.

IS4710 - Qualitative Methods. This research-seminar course has integrated the results of the FY05 Dillard-Nissen research into the students' course project.

Dillard, John T. "Centralized Control of Defense Acquisition Programs." IAMOT 2004 - New Directions in Technology Management: Changing Collaboration between Government, Industry and University. 3 -7 April 2004.

Dillard, John T. "Centralized Control of Defense Acquisition Programs: A Comparative Review of the Framework from 1987-2003." BPP Research Colloquium. 25 November 2003.

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